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AN APPROPRIATE TECHNOLOGY SOLAR WATER HEATER FOR REMOTE COMMUNITIES

Martin Anda and Goen Ho

1. INTRODUCTION

Ill-health in Aboriginal communities exists today in modern, affluent Australia and is well documented.

It appears that there has been some improvement in the infant mortality rate. For instance, in the Northern Territory the figure was 143/1000 in 1971 dropping to 30/1000 in 1981, which was still lamentable compared to the national rate in 1981 of 10/1000 (1). Today the growth of Aboriginal children in remote communites is still permanently impaired from widespread undernutrition, infections and trachoma (2). Adult mortality, however, is probably rising particularly as a result of 'lifestyle' diseases - heart disease, diabetes, obesity, alcoholism, accidents and violence.

It is widely acknowledged that to improve the conditions of health in Aboriginal communities an integrated approach to the provision of services, education and community-based and controlled health organisations is required (3) (4). Indeed many examples of successful work to date are amongst us today, e.g. The Centre For Appropriate Technology of Alice Springs and The Aboriginal Medical Service of Perth. Diseases prevalent in Aboriginal communities include diarrhoea, respiratory infections, pnuemonia, skin infections, trachoma, scabies and kidney disease. The prevention and cure of these are dependent, in physical terms, on medical services, reticulated water supplies for drinking and washing, shelter and nutritional food.

This project addresses the need for adequate washing facilities. While only one component of the required integrated approach, provision of hot water for washing will assist in overcoming the diseases listed above. Children under five years of age, for instance, should have the facilities to wash twice a day to minimise the incidence of these diseases (5).

2. WHY DESIGN AN ALTERNATIVE SOLAR WATER HEATER?

The following points serve as a basis for designing an alternative solar water heater:

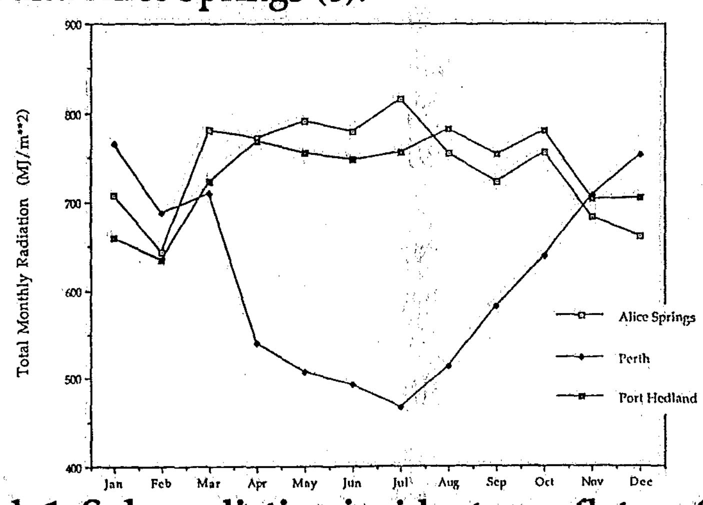
(i) The provision of hot water is necessary in cooler seasons for comfort which will motivate attention to hygiene.

(ii) Regular washing, particularly with warm water, will help prevent and treat the eye-disease trachoma and also skin diseases. (Trachoma has been reported to exist amongst 77% of Aborigines in Central Australia (4).)

(iii) The use of solar energy in small communities may offset the requirement for expensive, maintenance-intensive, diesel-engine power generation.

(iv) The establishment of a semi-sedentary, semi-traditional community in an arid environment will result in the depletion of local firewood resources and environmental degradation. A solar water heater will reduce the use of firewood for water heating.

The use of solar energy in northern and central Australia is highly attractive considering the large amount of year round radiation and the minimal presence of cloud. Solar thermal applications are particularly suitable here compared to the lower level of solar radiation received in southern cities during the winter season. Graph 1 below compares Perth to Port Hedland and Alice Springs (6).



Graph 1: Solar radiation incident on a flat surface facing north and tilted at 35^{o}C (6).

Commercial solar water heaters have suffered from a variety of problems in Aboriginal communities in the past (7):

(i) Freezing causes fracturing of copper tubes,

(ii) Maintenance services are not readily available within remote communities,

(iii) Glazing is smashed by stones,

(iv) Absence of electricity to boost supply on overcast days,

(v) Aboriginal people find difficulty relating to that technology in a meaningful way,

(vi) The quality of water in remote areas lends to a rapid build-up of deposits in the copper tubes, resisting flow or causing complete blockage.

Furthermore units are sometimes installed incorrectly, frames used for roof-mounting are often not strong enough and the capacity of older units was too small at around 100 litres. The UPK Report (5) resulting from studies carried out on the Anangu-Pitjantjatjara Lands found that 45% of hot water installations were not working for the various reasons already mentioned.

Modern solar water heaters have incorporated tempered glass and heat exchange to avoid breakage and corrosion or blockage of tanks and tubes respectively. Each of these add to the cost and complexity of the design. Heat exchange also reduces the performance of the unit. Some manufacturers recommend the use of non-heat exchange units with stainless steel tanks in the north-west where water quality is poor. The units then require maintenance every two years or so to flush out the deposits in the copper collector tubes. Such maintenance may not be available in remote Aboriginal communities.

To satisfactorily overcome most of the problems listed above plastics have been used in the design of this solar water heater.

This solar water heater has been designed with a view to utilizing technology that is both culturally and environmentally appropriate.

Appropriate technology criteria has been clearly identified in the past (8, 9). Equipment designed for use in remote Aboriginal communities should satisfy the following guidelines:

(i) Small, simple and cost-effective but able to withstand heavy, sporadic loading,

(ii) Integrated into whatever house or shelter design is preferred,

(iii) Technology that can be readily understood, installed and maintained by the community with minimal training and simple tools,

(iv) Suitable to be maintained and managed by women also and;

(v) Materials which are sturdy, readily available and either long-lasting or easily replaced in accordance with (3) above.

The use of plastics will satisfy the above guidelines. Moreover, this solar water heater design will aim to satisfy the Standards Association of Australia 'Class B' category of operation (10, 11). 'Class B' operation specifies that the solar water heater should be able to provide water at a temperature of 45^{o}C at the outlet with or without electric boost. The temperature ranges produced in such a system would be acceptable to the lower cost and readily available polyolefin plastics e.g. low and high density polyethylene, polybutylene and polypropylene. Commercial metallic units are typically designed to meet the 'Class A' category where 57^{o}C is required at the hot outlet. The higher range of temperatures experienced in such a system could not be sustained in the long term by polyolefins. More expensive plastics materials would have to be sought (see Section 6).

3. RESEARCH AND DEVELOPMENT IN 1988

During 1988 two working prototype solar water heaters were designed, built and tested (12). Each of these operated on the thermosyphon principle as utilised in most commercial units available today. One collector prototype was made from 100 x 2m, black, low-density polyethylene (LDPE), reticulation tubes. The complete unit is shown in Figure 1.

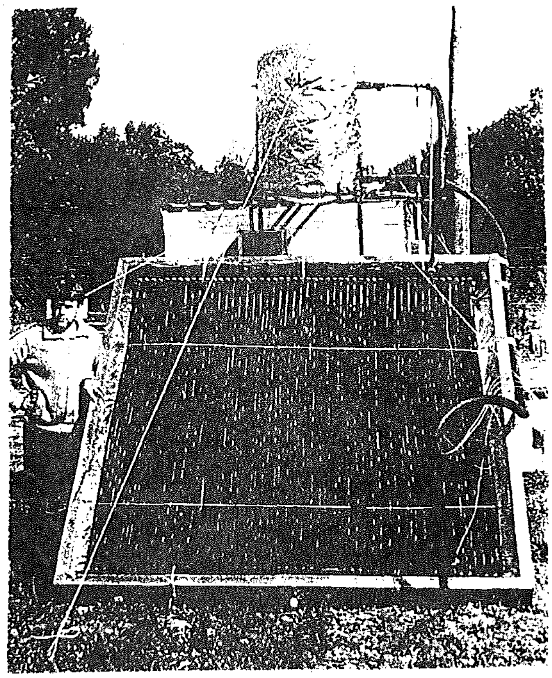


Figure 1: Unglazed tube-type solar water heater tested in 1988.

The tubes connected to upper and lower manifolds made from 90mm diameter high-density polyethylene (HDPE) pipe via threaded, slide-on nozzles. If a tube is blocked, split or cut - which is less likely than copper tube - it can be easily replaced. It is readily available at 50 cents/metre while copper is about $5/metre.

The other collector prototype comprised of 15 black, high-density polyethylene swimming pool heating panels - 'Solar Batts' - commercially available from the manufacturer in Melbourne or local suppliers at $10-20 each. The complete unit is shown in Figure 2.

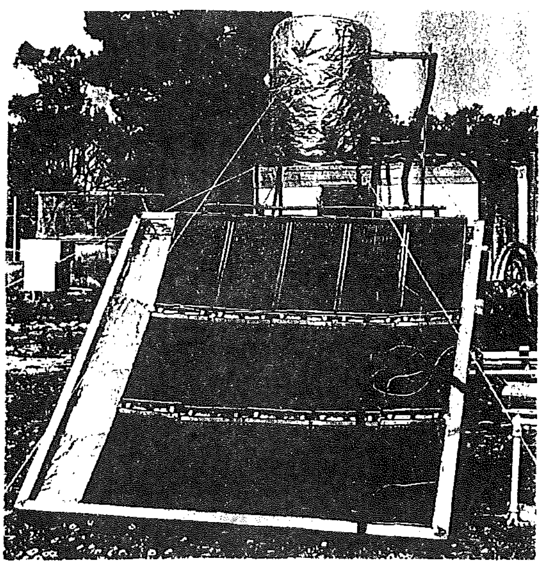
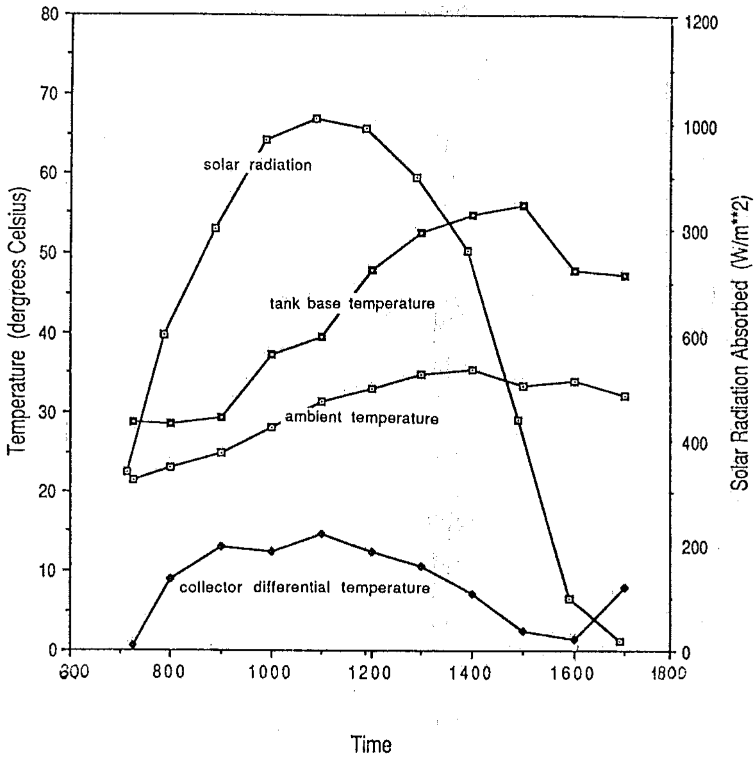


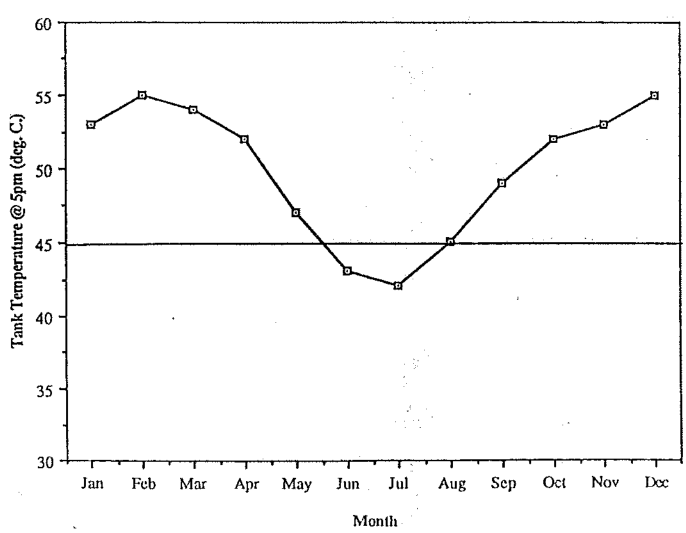
Figure 2: Unglazed Solar Batts system tested in 1988.

Both collector prototypes were connected to a vertically standing, 200 litre HDPE drum. Graph 2 shows the performance of the unglazed, Solar Batt collector in terms of temperature on a clear, sunny day in Newman.



Graph 2: Performance of the unglazed Solar Batts collector in Newman on 1st October with 50-litre draw-offs at 10am and 3pm.

There was not substantial difference in performance of the two types of collectors except the Solar Batts offer a faster response time. Based on the data obtained during 1988 we were able to make a prediction as to how the unit might perform during the whole year as shown in Graph 3.



Graph 3: Predicted annual temperature profile.

4. DESIGN DEVELOPMENT IN 1989

Research in 1988 indicated that an alternative SWH made from plastic could satisfactrily provide for domestic hot water demand. The subsequent industrial design phase yielded the concepts for the second prototypes.

The collectors proposed utilise the same principles, i.e. the LDPE tubing and the HDPE Solar Batts. The first collector shown in Figure 3 utilises 13mm diameter LDPE reticulation tubing and fittings as the absorber. The diameter of the tubes have been reduced from the 19mm used in 1988 to reduce the thermal inertia. The manifolds have been modified to neoprene grommet connections instead of labour-intensive and leak-prone threaded directors. Ultimately, however, the optimum solution would be to injection mould the manifold. The design can be used with or without glazing. A woven polyethylene greenhouse fabric will be used in testing.

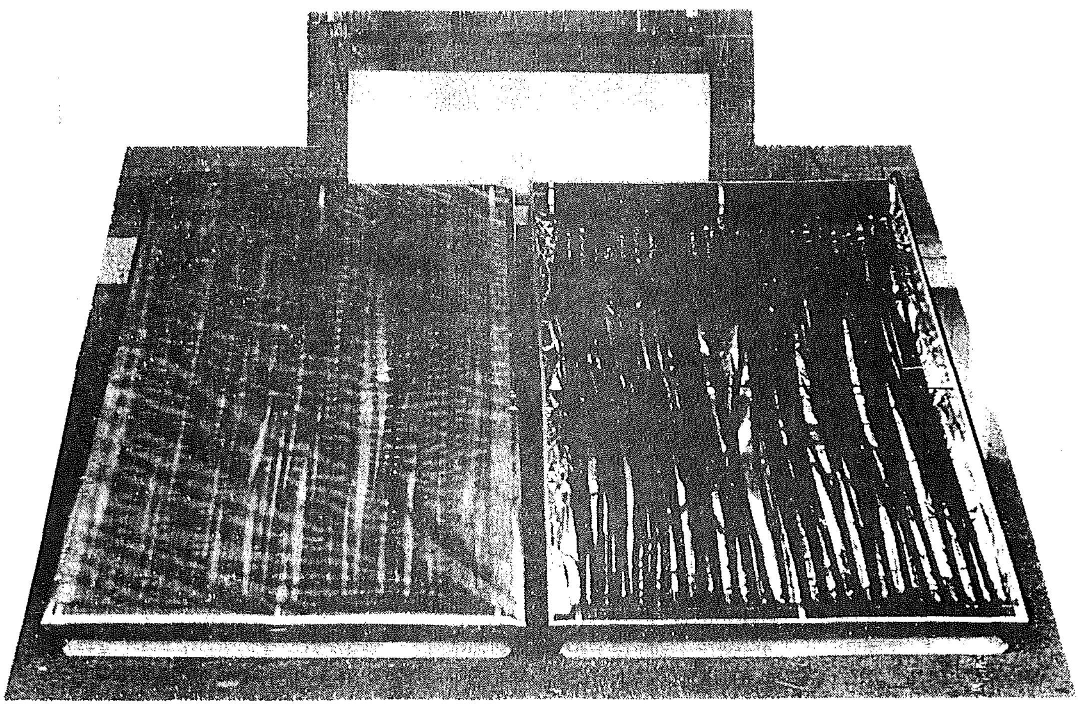


Figure 3: Glazed tube-type solar collector

The second collector shown in Figure 4 comprises 12 Solar Batts in two conveniently sized panels. The manifolds and interconnecting pipework are constructed from the polybutylene, Qest-Dux, Quicksert piping system which is suitable for mains pressure and continuous use at 90^{o}C. The Solar Batts themselves could have their nozzles modified to utilise the Quicksert connection system. Discussions are underway with Solar Batts and Qest-Dux on this matter. The glazing is an acrylic cover to each batt. The batt could later be modified to more effectively integrate the cover for convenience and to reduce stresses.

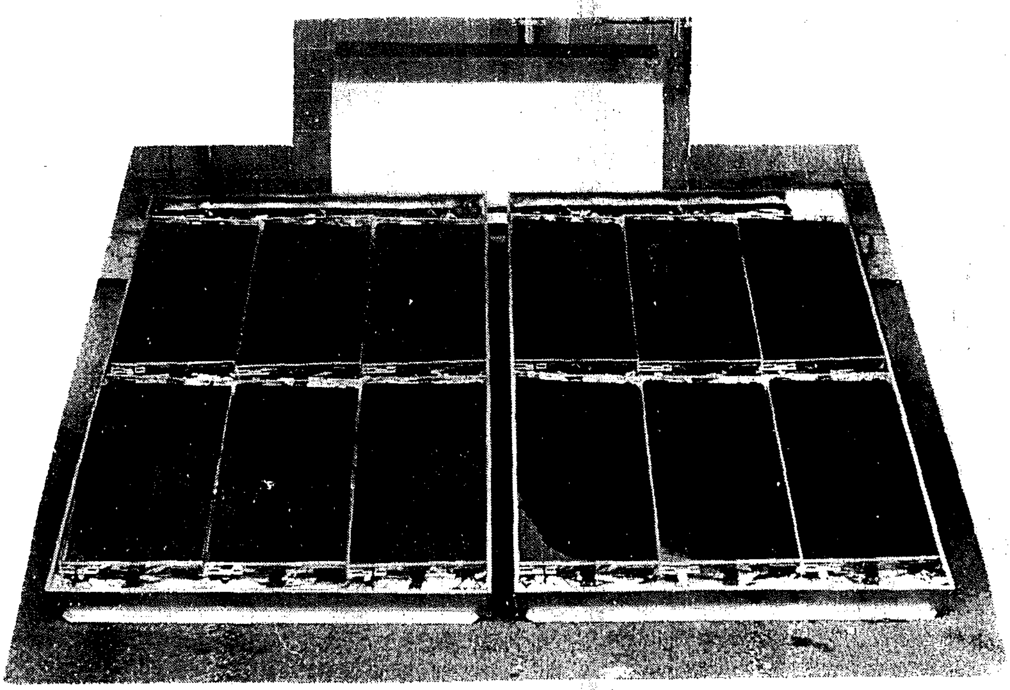


Figure 4: Glazed Solar Batts collector

The LDPE collector would be ideal to develop due to its simplicity and low cost. However the durability and longevity of the LDPE with the high temperatures attained with glazing needs to be ascertained. Without glazing the 'Class B' status of Australian Standards, where 45^{o}C continuous hot outlet is required, may not be achieved. Development of the Solar Batts to 'Class B' status is more likely. A 'Class A' design, where 57^{o}C continuous hot outlet is required, is also being investigated. More advanced plastics would need to be used. To enable comparison the cost of different tubes are: LDPE \$0.50/m, polybutylene \$3/m and copper \$5/m. The cost of the raw plastics are typically \$2 - \$4/kg for the polyolefins (LDPE, HDPE, PB, PP) and \$6 - \$8/kg for the more advanced plastics that would be required in a 'Class A' unit.

The storage tank shown in Figure 4 is a 200-litre, high-density, polyethylene Mauser drum manufactured by Rheem Australia Ltd. The tank outlets are HDPE standard fittings used commercially for various plastic containers. An electric element heater and thermostat have been fitted to comply with the testing procedures of AS 2984 - 1987. In the final design all outlets on the tank could form part of the moulding.

Moreover, plastics such as polypropylene may have to be used in the moulding to satisfy 'Class B' criteria. Discussions are currently underway with various manufacturers on this matter.

The UPK report (5) has recommended that for Aboriginal communities the minimum storage tank size be 300 litres. Larger 'off-the -shelf' plastic drums will be sought and the final design should attempt to satisfy this sizing requirement.

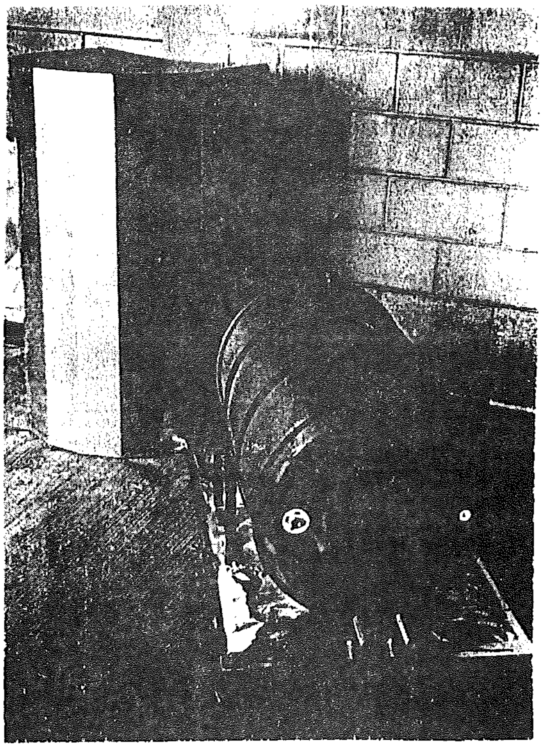


Figure 5: Storage tank

The casings have been designed for modularity and portability and, of course, to contain the collectors and tank in the most compact fashion.The cheapest and most convenient material of construction for the prototype casings was galvanised sheetmetal. In production fibreglass may be more appropriate due to its light weight. Although this material is more expensive the manufacturing equipment it requires is substantially lower, i.e. sheetmetal shears, presses and rollers c.f. timber moulds.

The insulation used in all the casings is 50mm fibreglass with a layer of reflective foil. This is very convenient for fabrication of the prototypes and while being reasonably durable, the use of polyurethane applied as rigid sheets or poured as liquid to set will be cheaper and more appropriate in production.

5. PROPOSED TESTING

At this stage it is envisaged that the test method employed will be that given by the Standards Association of Australia (11). "This Standard sets out a method of determining the performance of a solar water heater heating system under natural outdoor conditions and prescribes a method of transforming the test results from the particular climate conditions of the test to long-term average conditions for the test location or for other locations with similar solar irradiation conditions... The Standard applies only to systems with an auxiliary heating system that can satisfy the load under no-solar input conditions." The storage tank prototype will include an electric element heater for testing but this may not necessarily be included in the final design for an appropriate technology unit.

The Standard requires the following parameters to be measured:

a) delivered hot water flow rate
b) supplementary energy used
c) timing to a standard pattern of hot water demand.
c) thermal demand in three seperate temperature categories.
d) cold water supply temperature
e) hot water delivery temperature.
f) solar irradiation
g) ambient air temperature
h) wind speed

The Standard produces results of the system performance essentially in the form of solar fraction, supplementary energy fraction and energy savings relative to a conventional water heater.

The following instrumentation will be used:

a) needle valve set to deliver 12.5 L/min from the hot outlet at specified time.
b) thermostatically-controlled electric heater element with a watt-hour meter.
c) hot outlet thermocouple.
d) cold water supply thermocouple.
e) pyranometer in the plane of the collector.
f) shaded thermocouple outdoors.
g) wind anemometer.

The instruments will be connected to data loggers for field storage of information.

Additional testing will also be carried out on various components of the prototypes. For instance, the manifold design of the LDPE collector has already been hydraulically tested to 170 kPa (25 psi). This will be adequate for a low-pressure unit. Other tests to be carried out include subjecting the completed storage tank and Solar Batts to elevated temperatures and pressures and accelerated aging on the plastics.

6. CHOICE OF MATERIALS

Plastics:

Solar water heaters manufactured by Solahart are sold with a guarantee of five years; those of Small's have a guarantee of six years and those of Edwards' seven years. These products typically have a service life of eight to fourteen years depending on water and installation conditions and provided they receive the scheduled preventative maintenance. In remote areas the useful life of the units may be substantially less.

Plastics materials have already exhibited their durability in the application of swimming pool solar water heating. A range of products have been developed for this market and include the use of polyethylenes, plasticised PVC and EPDM (ethylene propylene rubber). A plastic solar water heater would have a service life in excess of ten years.

AS 2698.1-1984 prescribes that LDPE tubing can be in service at 60^{o}C and at a working pressure of 0.10 MPa. The LDPE heat distortion temperature of 40^{o}C has been quoted as a continuous service temperature (5). Table 1 quotes different sources for the continuous service temperature of LDPE as being in the range of 40-75^{o}C. Table 2 anticipates the maximum unglazed collector temperature to be 75^{o}C. A glazed collector may produce short term temperatures slightly higher than this. Testing is required to determine if LDPE is satisfactory for a 'Class B' operation solar water heater absorber requiring long-term durability.

Table 1: Temperature data for plastics

Temperature (degrees Celsius)	LDPE Tubing.	HDPE Solar Batts, storage tank, manifolds.	Poly -butylene Tubing.	Poly -propylene Fittings.
Melting	110	130	125	
Short term	75	90	100	110
Maximum continuous service	40 - 75	60 - 90	90	90 - 100
Heat Distortion	40	60		100

Table 2: Experimental data

Location: Newman; Latitiude: 23^{o}South; Month: September; Glazing: none.

Temperature	degrees Celsius
Maximum expected collector stagnation (November):	75
Maximum calculated collector stagnation:	66
Maximum measured collector stagnation:	66.2
Average monthly maximum:	29.2
Typical cold water inlet:	30
Typical hot water outlet at 5pm - LDPE tubing:	48
Typical hot water outlet at 5pm - HDPE Solar Batts:	50

Hoechst are able to confirm that their HDPE will maintain durability for 10 years at 60°C and with a hoop stress of 1.3 MPa. AS 1159-1988 prescribes HDPE pressure pipe as having a life expectancy of 50 years at 20°C and 0.6 MPa working pressure. Table 1 refers to a continuous service temperature of 60-90°C. With regard to the Solar Batts which are made from HDPE, independent tests have been carried out on these by the CSIRO and the Victorian Solar Energy Council prior to their comissioning in swimming pool heating systems. The batts were subjected to cycling at 115°C under the AS 2712 stagnation test. Such information indicates that HDPE would be durable enough for most of the components in a 'Class B' solar water heater.

Table 1 provides the temperature characteristics of the various polyolefins proposed for the project. "All the types of materials shown above [LDPE, HDPE, uPVC, ABS (acrylonitrile butadiene styrene) polymers, polypropylene], if suitably formulated will withstand boiling water intermittently. Polypropylene has a minimum anticipated life of ten years at a constant 60°C" (5). There would be no doubt about polypropylene having the required durability for a 'Class B' solar water heater. AS 2642.2 specifies 20mm, Class 16, polybutylene tubing as being able to operate at 80°C at a working pressure of 0.76 MPa. It has been shown that these conditions would yield a life expectancy of 50 years (National Standing Committee on Plumbing and Drainage - 1985). The Building Research Association of New Zealand (1981) certifies polybutylene tubing for continuous use at 100°C and 0.48 MPa.

These plastics may also prove to have the durability required in a mains-pressure 'Class A' unit. Certainly, plastics materials are available that can be used in place of polyolefins with superior temperature and pressure characteristics. The thermoplastic alloy of polyphenylene oxide(PPO) modified with high impact polystyrene (General Electric-Noryl), for example, has a continuous use temperature of between 85-110°C. Other sources quote PP/PPO mouldings and thermoplastic sheets (e.g. ABS) as suitable for solar collectors (5).While the polyolefins wholesale at $2-5/kg, these more advanced plastics cost $6-8/kg and their economically-viable use in the final product would depend on the manufacturing technology employed.

Glazing:

Initially, an aim of the project was to produce an unglazed collector to avoid breakage, minimise the total cost and reduce the manufacturing complexity. It appears likely from the 1988 results that an unglazed collector would not provide adequate heating all year round. By introducing semi or full glazing to the collector additional heating is achieved by the 'greenhouse effect' but the collector materials are subjected to higher temperatures and hence more rapid degradation. The extent of glazing and plastic materials used for the collector absorber need to be evaluated to achieve reasonable life expectancy without excessive costs.

Table 3: Glazing materials characteristics

Material	Light Transmission	Resistance to Impact	Heat Transmission	Flammability	Life Expectancy	Cost $/m^2	Cost/ life
Polycarbonate	0.86	Very good	0	Does not burn	10	100	10
Tempered glass	0.77	Fair	0	Does not burn	25	70	3
Acrylic	0.88	Fair to good	0	Burns readily	10	50	5
PVC	0.89	Fair	0	Does not burn	7	24	3.5
Fibreglass	0.85	Good	0	Burns	8	12	1.5
Woven or reinforced polyethylene	0.88	Good	0.55	Burns and melts	3	3	1

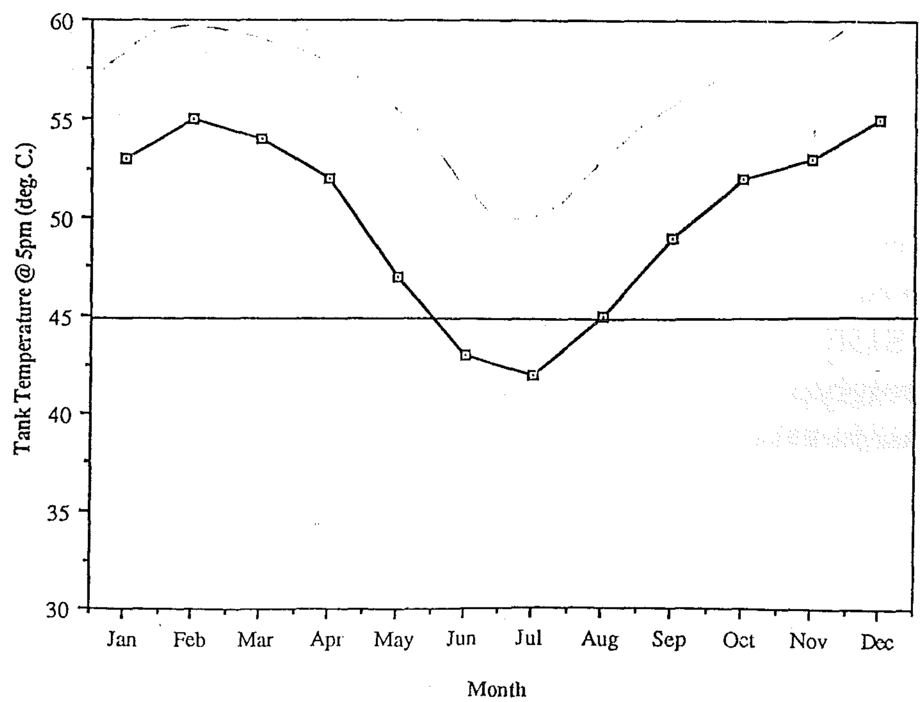
Woven polyethylene sheeting ('Solarweave' by Rheem) will be applied to the LDPE collector such that it fully covers the aperture and seals at the edges. The material is cheap, easily applied, reasonably strong due to the weave and coating and will allow some heat to escape. It has the lowest cost/life ratio (see Table 3).Testing will need to establish whether, while allowing this transmission, excessive temperatures will still be reached by the LDPE. The woven polyethylene film only has a life expectancy of three years but can be easily replaced without specialist skills or tools.

Specially fabricated acrylic covers will be applied to the Solar Batts. These are shown in the design drawings. The simpler and cheaper alternative is to use a sheet of acrylic across the full aperture of the collector. However, the individual treatment means that if one cover breaks or degrades the 'greenhouse effect' will still be retained in the other batts. Moreover, each batt can be accessed individually for replacement or maintenance if necessary. If successful, the batt moulding could be modified so that the acrylic cover becomes an integral attachment. This will also reduce the stresses in the acrylic thereby minimising the risk of fracture from a striking stone. Acrylic has the unique property of shielding the ultraviolet component of the solar spectrum thereby increasing the life of the material beneath it. The cost/life ratio (see Table 3) is not so attractive but it would have manufacturing advantages in addition to those already cited.

Forms of ventilation can be included to the collector casing if the greenhouse heating proves to be too excessive for the plastics. For example: A small area of the upper and/or lower casing sides could be fixed louvres with the open area calculated to allow a certain convective air flow volume for a given temperature rise and friction drop.

7. THE WORK AHEAD

Thorough testing of the SWH prototypes will be carried out to enable comprehensive prediction of the performance. However, experience indicates that glazing and improvements to the 1988 prototypes should provide at least 5-10^{o}C higher temperatures as shown in Graph 4.



Graph 4: Predicted annual temperature profile for 1989 prototypes

Further modifications are required to the prototypes before a unit can go into the field. They would include the following:

1) Polybutylene will oxidise in continuously circulating hot water systems reducing its useful life to 4-5 years. The primary circuit of the SWH should be replaced with HDPE pipe and fittings.
2) HDPE will creep over time at elevated temperatures. A 200-300 litre polypropylene storage tank is being sought.
3) A singular casing and support structure will be designed for the storage tank.
4) Polyurethane foam will be used in the tank and collector casings for greater insulation, ease of manufacture and lower cost.
5) The tubing collector manifolds could be injection moulded in a single piece or several standard pieces.
6) Modifications to the Solar Batts moulding could be to the nozzle connections so that they become compatible with the HDPE pipe fittings and to enable easy attachment of the glazing covers.
7) Moulding of the Solar Batts could be investigated for improved longevity and durability at higher temperatures produced by glazing.
8) Glazing to both collectors should be optimised.

After the next round of testing and modifications it is hoped that pilot studies can be initiated in one or two communities.

Some approximate cost comparisons are worthwhile although an exact figure can certainly not be placed on the plastic SWH prototypes currently under development. A gas or electric storage water heater of 180-litre capacity costs around $800 and will typically last 10-15 years in the city and possibly 5-10 years in remote areas. A solar water heater of 180-litre capacity with tempered glass and anti-freeze equipment costs around $1500 and will have similar lifetimes to the storage heaters. The SWH prototype under development would cost approximately $900 and could last in excess of 10 years in remote areas.

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